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FOUR COLOR IMAGE SENSING APPARATUS

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FOUR COLOR IMAGE SENSING APPARATUS

CROSS REFERENCE TO RELATED APPLICATIONS

Reference is made to commonly-assigned copending U.S. Patent Application Serial No. ___________ (Attorney Docket No. 83529), filed herewith, entitled FOUR COLOR FILM WRITER, by Roddy et al., the disclosure of which is incorporated herein.

FIELD OF THE INVENTION

The present invention relates in general to color imaging apparatus and in particular to electronic cameras employing receptors for four colors to increase the color gamut of the captured image.

BACKGROUND OF THE INVENTION

Recent electronic camera designs typically use planar CCD and CMOS type sensors. In order to provide a succession of color image frames wherein each frame has full color content using these sensor types, one of two approaches is used. In one method, three separate sensor arrays are provided, with either a red, a green, or a blue filter in front of each sensor array. Alternatively, a prism could be used to split incoming light into three colors, with each color provided to a separate, unfiltered sensor array. This first method provides a tristimulus red, green, and blue (RGB) value for each pixel.

A second method uses a single sensor array and places a color filter array (CFA) over the sensor array such that a red, a green, or a blue filter lies over each sensor of the sensor array. With this second method, since the full tristimulus RGB value is not obtained from each sensor of the sensor array, interpolation is used to calculate missing values, based on the matrix of values obtained. The second method has been used for lower resolution sensors, especially for consumer still cameras, so that images obtained on these cameras can be output easily to printing and display devices in standard TIFF or BMP (bitmap) formats. Although the second method may introduce some unwanted effects in an image under certain conditions, this method has the advantage of eliminating color misregistration errors associated with misalignment of multiple sensors and is often used for generating NTSC television signals.

Yet another method is available when using a single sensor, but does not provide simultaneous RGB color content. This third method employs a field sequential camera with a single sensor and a rotating color filter wheel with red, green, and blue filters.

Among patents that describe interpolation techniques used with the second method given above, U.S. Patent No. 3,971,065 (Bayer) discloses a color imaging array wherein a mosaic of selectively transmissive filters is superimposed in registration with a solid imaging array. In a preferred embodiment, each row contains alternating filters for luminance and a first chrominance and alternating rows contain luminance filters alternating with a second chrominance filter. The advantage of this approach, wherein there are twice as many green pixels as red or blue pixels, is that a higher resolution is obtainable in green, to which the eye is most sensitive. Green sensitivity is also most closely related to the luminance channel value for a color image. As is well known in the imaging arts, the human eye is most sensitive to luminance and much less sensitive to chroma information. Thus, luminance data is important in NTSC color transmission used for color TV, for example. Other examples of interpolation techniques used with digital color cameras that employ CFAs are disclosed in U.S. Patents No. 5,990,950 (Addison) and 6,181,376 (Rashkovskiy et al.)

For video camera applications, U.S. Patent No. 5,251,019 (Moorman et al.) discloses a solid state color image sensor used with a CFA. The color filter array in U.S. Patent No. 5,251,019 covers an array of image sensor elements wherein 75% of the image sensing elements are luminance sensing, for example, green elements, and the rest are chrominance sensing, for example, red and blue elements.

With the goal of improving image quality, there have been a number of solutions proposed for improving the RGB sensitivity of digital color cameras. As one example, instead of using a color filter array (CFA) of red, green, and blue (RGB) filters, using a filter array of cyan, magenta, and yellow (CMY) filters has been proposed, as noted in U.S. Patent Nos. 5,631,703 and 6,330,029 (Hamilton et al.) Accurate RGB values can then be derived algebraically from the CMY values. It is further noted in the latter patent as an

advantage of such a filter technique that twice the amount of energy falls on each pixel as compared to the RGB color filter array (CFA). For example, cyan transmits both blue and green light, so that the detector cell would see twice as much light as it would with either a blue or a green filter. This advantage provides a better signal to noise ratio for a given cell size and integration time. In a preferred embodiment, because luminance information is derived from the green channel, an additional green filter is also added to the cyan, magenta, and yellow filters to provide a better interpolation of RGB values for each pixel.

In another attempt to improve camera performance with various light sources while minimizing interpolation artifacts, U.S. Patent No. 5,889,554 (Mutze) discloses the use of five color filters and preferred patterns for arranging them. The preferred colors are B (455nm), G' (494nm), G (545nm), G' (570nm), and R (595nm). The extra colors aid in improving the interpolation of RGB values for each pixel; no additional color data is provided.

With the goal of improving CCD sensor performance through device manufacturing techniques, U.S. Patent No. 6,001,668 (Anagnostopoulos) describes the use of transparent ITO electrodes in sensor fabrication. With a similar goal, U.S. Patent Nos. 5,677,202 and 5,719,074 (Hawkins et al.) disclose improved methods of manufacturing CFAs onto CCDs.

The above cited patents show attempts at improving color quality of digital color images by making incremental improvements to the RGB data as acquired and processed by a digital camera. Referring to Figure 10, there is shown a familiar graphical representation of the human-visible color gamut, shown as a horseshoe-shaped periphery 100. Within periphery 100 are represented two smaller color gamuts: a motion picture film color gamut 102 and an NTSC TV color gamut 104. It is instructive to note that the color gamut is essentially defined by a triangle, where each vertex corresponds to a substantially pure color source, ideally a primary color, that serves as a component color for other colors within the gamut. The area of the triangle thus represented corresponds to the size of the color gamut. To expand color gamut requires moving one or more vertices closer to periphery 100.

Conventional color models, such as the CIE LUV model that follows the color space conventions defined in 1931 by the Commission Internationale de l'Eclairage (International Commission on Illumination), represent each individual color as a point in a 3-dimensional color space, typically using three independent characteristics such as hue, saturation, and brightness, that can be represented in a three-dimensional coordinate space. Color data, such as conventional image data for a pixel displayed on a color CRT, is typically expressed with three-color components (for example R, G, B), that is, in tristimulus form. Conventional color projection film provides images using three photosensitized emulsion layers, sensitive to red, blue, and green illumination. In fact, the human eye itself has three-color sensors, R, G, B. Because of these conventional practices and image representation formats, developers of cameras, films, printing apparatus and display systems have, understandably, adhered to a three-color model.

There have been some attempts to expand from the conventional three-color model in order to represent color in a more accurate, more pleasing manner. Notably, few of these attempts are directed to expanding the color gamut. For example, the printing industry has used a number of strategies for broadening the relatively narrow gamut of pigments used in process-color printing. Because conventional color printing uses light reflected from essentially white paper, the color representation methods for print employ a subtractive color system. Conventionally, the process colors cyan (blue + green), magenta (red + blue) and yellow (red + green) are used for representing a broad range of colors. However, due to the lack of spectral purity of the pigment, combinations of cyan, magenta and yellow are unable to yield black, but instead provide a dark brown hue. To improve the appearance of shadow areas, black is added as a fourth pigment. As is well known in the printing arts, further refined techniques, such as undercolor removal could then be used to take advantage of less expensive black pigments in full-color synthesis. Hence, today's conventional color printing uses the four color Cyan, Magenta, Yellow, and blacK (CMYK) method described above. However, even with the addition of black, the range of colors that can be represented by printing pigments is limited.

Other examples showing where additional color components have been added to improve color appearance are from digital projection apparatus. U.S. Patent No. 6,256,073 (Pettit) discloses a projection apparatus using a filter wheel arrangement that provides four colors in order to maintain brightness and white point purity. However, the fourth color added in this configuration is not spectrally pure, but is white in order to add brightness to the display and to minimize any objectionable color tint. It must be noted that white is an "intra-gamut" color addition; in terms of color theory, adding white actually reduces the color gamut by desaturating the color. Similarly, U.S. Patent No. 6,220,710 (Raj et al.) discloses the addition of a white light channel to standard R, G, B light channels in a projection apparatus. As was just noted, the addition of white light may provide added luminosity, but constricts the color gamut. U.S. Patent No. 6,191,826 (Murakami et al.) discloses a projector apparatus that uses four colors derived from a single white light source, where the addition of a fourth color, orange, compensates for unwanted effects of spectral distribution that affect the primary green color path. Again, the approach disclosed in the Murakami patent does not expand color gamut and may actually reduce the gamut.

Unlike the earlier patents listed above for projection apparatus, Patent Application WO 01/95544 A2 (Ben-David et al.) discloses a display device and method for color gamut expansion using four or more primary colors. However, while the methods and apparatus disclosed in application WO 01/95544 provide improved color gamut for projected images, the image data that is originally input to the projection device is tristimulus RGB data, not four-color data.

Thus, it can be seen that it would be advantageous to provide a camera which could provide a signal having a fourth color that would result in an improved color gamut. Such a signal could be input to a projector mechanism or printing device that could take advantage of this extended gamut and provide a more pleasing image.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide the widest gamut input data to four color cinema, television display, or four color writer. A four-color capture of the input scene is desirable.

Briefly, according to the present invention a color image device comprises an array of sensitive light elements. A first type of element is sensitive to a blue spectral region. A second type of element is sensitive to a red spectral region. A third type of element is sensitive to a green spectral region. A fourth type of element is sensitive to a fourth portion of the spectral region.

In the present invention, capture could be done using existing CCD or CMOS imagers. One method is to have four cameras, each with a separate spectral filter in front of it. A second method is to have a rotating filter wheel in front of a single camera that has four spectral bandpass filters. A third method is to have four sensors in a camera, and spectrally separate the light with dichroic filters. In a fourth method, a CCD or CMOS sensor with an integral four color filter array, similar to the three color filter arrays in present use, would provide a suitable solution. Present color filter arrays (CFA) are provided for RGB operation or for the light-efficient CMY operation, and could be suitably modified to incorporate a fourth passband.

The invention and its objects and advantages will become more apparent in the detailed description of the preferred embodiment presented below.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph which shows the color gamut available from a four color projector using input signals from a four color camera;

Figure 2 is a top view of a four camera, four filter system;

Figure 3 shows a camera using a field sequential single sensor with a rotating filter wheel;

Figure 4 is a top view schematic of a 4 sensor camera with dichroic filter spectral bandwidth separators;

Figure 5 is a top view schematic of a 4 sensor camera with an x-cube color splitter;

Figure 6 shows an arrangement of RGCB filters in a color filter array;

Figure 7a shows a camera with 2 sensors, one with a G, C filter array and one with a R, B filter array;

Figure 7b shows a camera with 2 sensors, one with a R, G filter array and one with a C, B array;

Figure 8a shows an arrangement of G and C filters in an array;

Figure 8b shows an arrangement of R and B filters in an array;

Figure 8c shows an arrangement of R and G filters in an array;

Figure 8d shows an arrangement of B and C filters in an array;

Figure 9 is a top view of a camera with a single photosensor having a multicolor CFA; and

Figure 10 is a graph showing the conventional color gamut for motion picture film and NTSC TV signals.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will be directed in particular to elements forming part of, or in cooperation more directly with the apparatus in accordance with the present invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

Referring now to Figure 1, there is shown a CIE chromaticity diagram in u', v' coordinate space wherein horseshoe shaped periphery 100 shows the limits of gamut defined by human color vision. Note that a four sided polygon 106 defined by the four vertices 116, 114, 112, 108 of red, green, blue, and blue-green saturated primary colors encompasses a color gamut almost equal to that of the human visual system. A display using four light sources would be capable of forming images using this enhanced color gamut, and providing a more faithful reproduction of an original scene, but it optimally requires a fourth color signal that is not available with conventional camera devices. Simply stated, a four-color display requires a four-color camera.

In order to provide fourth color scene information, for example, blue-green, to a blue-green color modulator, it is desirable to record a separate color channel in the camera which captures the scene. This requires a camera that captures red, green, blue, and a fourth primary color C (RGBC) where C is typically blue-green or cyan. The cyan information described here can be of

narrower spectral bandwidth than that transmitted by a typical cyan filter, which covers all of the blue and all of the green spectral region. Such a camera could have a number of different possible arrangements, for example, with four sensors, one sensor for each color, with two sensors, each sensor shared by two colors, or with a single sensor having a color filter array for which an R, G, B, C, value could be determined for each pixel location, or with a single high resolution sensor with a four color CFA that outputs data to four color channels.

One method of providing RGBC data is shown in the embodiment of Figure 2. Four cameras 20R, 20G, 20BG, and 20B are aligned to a scene 14, each camera having a separate color filter 10R, 10G, 10BG, 10B respectively, positioned in front of it. A lens 15 images scene 14 onto an appropriate area array photosensor 30R, 30G, 30BG, 30B. The advantage of this arrangement is high resolution imaging in each color, R, G, B, C. A difficulty with this arrangement, in addition to cost, is the task of keeping all four cameras registered.

A second embodiment is shown in Figure 3, wherein a single camera 20 with a single area array photosensor 30 is used with a color filter wheel 25 containing red 10R, green 10G, blue-green 10BG, and blue 10B filters positioned in front of the camera and a color sequential signal produced. Color filter wheel 25 can be replaced by an electronically switchable LCD color filter such as devices made by ColorLink Inc., Boulder, Colorado. This type of color filter is typically operated between crossed polarizers (not shown).

Referring again to Figure 3, camera 20 comprises an image acquisition unit 120 that contains the optical and electronic components for focus, sensing, and initial light acquisition. A signal processing unit 126 accepts and processes the sensed data values from photosensor 30. For the apparatus shown in Figure 3, signal processing unit 126 processes the sequential color data that is output from imaging acquisition unit 120. A control logic processor 122, typically a microprocessor or equivalent logic processing device, coordinates and controls the acquisition of image data and the interaction of image acquisition unit 120 and signal processing unit 126. An image data storage device 124 stores the final four-color data that is obtained for each image pixel.

A third embodiment is shown in Figure 4, wherein camera 20 has four area array photosensors 30, and white light 16 from a scene is spectrally divided for the four sensors 30R, 30G, 30BG, 30B, one each for red, green, blue-green, and blue. White light 16 passes through lens 15, and is divided by a dichroic mirror 32 into red light and blue-green light. The red light, in this case, reflects from dichroic mirror 32 and impinges onto CCD array 30R. The blue, green, and blue-green light is transmitted to a beamsplitter 36, which could be a pellicle or partially silvered mirror, for example. Beamsplitter 36 does not have to divide the light equally. For example, two-thirds of the light could be directed to the blue sensor and the green sensor and one-third of the light could be directed to the blue-green sensor. Blue and green light are reflected from beamsplitter 36 and directed toward a dichroic mirror 34. Blue-green light is transmitted through beamsplitter 36 and goes to blue-green area array photosensor 30BG. Dichroic mirror 34 then transmits blue light to blue area array photosensor 30B and reflects green light to green area array photosensor 30G. It is instructive to note that each photosensor 30 can be separately tuned to a suitable sensitivity value for the level of incident light.

A fourth embodiment is shown in Figure 5, wherein an X-cube 38 is used to separate the s-polarized red and blue colors (denoted by the dots) from the incoming light from lens 15. A filter 32 reflects red, blocking red light that may leak through X-cube 38 and passes blue and green. A dichroic mirror 34 is used to complete and clean up the color separation. The x-cube passes green of both polarizations (as shown by the dot and the arrow) and will also pass s-polarized (arrow) blue and red light. Dichroic filter 34 is designed to reflect the remainder of the blue and the shorter wavelengths of the green light to blue-green sensor 30BG. The balance of the green light is transmitted to green sensor 30G.

Figure 6 shows a preferred arrangement of RGBC filters in a color filter array. In one embodiment, fourth color C is cyan, the blue-green filter that can have a narrower bandwidth than the full blue and green spectra, which ranges from the 400 to 600nm normally be associated with cyan. For example, a suitable cyan filter may have a passband of 470 to 530 nm. The green and blue-green filters can be used to represent the luminance signal, and are alternated with red

and blue. In this way, the "luminance" signal will have higher resolution than the red and blue "chrominance" signals. The filters are arranged in a manner similar to that shown in U.S. Patent Nos. 5,631,703 and 6,330,029 so that interpolation is improved and that good resolution is maintained in the diagonal direction, as well as vertical and horizontal directions. Such a sensor can be incorporated in a camera similar to that illustrated in Figure 9.

Figure 7a shows image acquisition unit 120 in camera 20 which uses two area array photosensors 40, 42, each with a separate color filter array. Here, array photosensor 42 has a combination of G and C filters and can be used directly as the luminance signal because the eye is most sensitive to these wavelengths. The other sensor, array photosensor 40 has R and B filters. The light entering the camera passes through lens 15 and is imaged on one of the two array photosensors 40, 42. Some of the light is transmitted by beamsplitter 36 and is imaged onto the array photo 42 sensor having a green and blue-green color filter array. The remainder of the light is reflected to array photosensor 40 having a red and blue color filter array. Beamsplitter 36 can be a mirror, pellicle, or a dichroic mirror. A dichroic device may be more expensive but has the advantage of light efficiency and possibly improved contrast. Beamsplitter need not be 50-50 with reflect to reflected versus transmitted light. More light could be directed to one detector or the other to compensate for detector response.

A hybrid design for camera 20 with two area array photosensors as shown in Figure 7a is a compromise between the four sensor camera of Figures 4 and 5 which is harder to align but needs no interpolation and a single sensor camera as in Figure 3 which is much easier to align but is neither as accurate in color rendition nor as high in resolution. However, the two array camera can be more compact and less expensive than the four color device and does not require expensive prisms or dichroic components.

Figure 8a shows a preferred arrangement of G and B-G filters in a CFA for use in a camera illustrated in Figure 7a. Figure 8b shows a preferred arrangement of R and B filters in a CFA for use in a camera illustrated in Figure 7a.

In comparison with Figure 7a, Figure 7b shows image acquisition unit 120 having R and G filters on area array photosensor 46 and C and B filters on area array photosensor 48, grouping the filters by closest wavelength. This arrangement may be the most advantageous with respect to dichroic beamsplitter 36 design, since all wavelengths above a threshold are reflected, and all wavelengths below the threshold are transmitted. In contrast, the arrangement of Figure 7a transmitted wavelengths toward the middle of the visible spectrum, reflecting higher and lower wavelengths. Figure 7a would thus be optimal for an imaging system such as NTSC using luminance information. It should be noted that the colors reflected and the colors transmitted shown in Figures 7a and 7b could be reversed. Not all imaging systems require a TV style signal based on luminance and chrominance. Where broadcast bandwidth is not an issue, as with digital cinema projectors and color printers, the R, G, C, B signals can be used directly.

The filter arrays needed for the camera illustrated in Figure 7b are constructed as shown in Figures 8c and 8d.

Figure 9 shows an alternate embodiment of camera 20 where imaging lens 15 images light from scene 14 (not shown in Figure 9) onto a multicolor color filter array photosensor 60. Photosensor 60 might use an array configured as that shown in Figure 6 as an RGBC CFA. It could have any of a number of other configurations including a CMY array. The red, green and blue signals can be derived algebraically from the CMY signals and the blue-green signal can use a scaled version of the cyan signal.

Deriving RGBC from CMY filter signals:

R=M+Y

G=C+Y

B=C+M

BG=C

These signals are then combined electronically in the signal processing unit 126 to provide a four color image, which has an increased color gamut.

Another filter that be used in the camera of Figure 9 is a variation of the Moorman filter. The Moorman filter is arranged as follows:

G G G R

G R G G

G G G B

G B G G

Some of the G filters can be replaced with a C filter which represents blue-green, for example:

G C G R

G R G C

G G C B

C B G G

Rearranging for better diagonal response:

C R G G

G C G B

G G C R

B G G C

For processing of data obtained from CFA filtering for four colors and interpolation of color values, methods similar to those presently used with three-color systems can be employed.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the scope of the invention.

PARTS LIST

10R. Red filter

10G. Green filter

10BG. Blue-Green filter

10B. Blue filter

14. Scene or object

15. Lens

16. White light

20. Camera

20R. Red channel camera

20G. Green channel camera

20BG. Blue-Green channel camera

20B. Blue channel camera

25. Color filter wheel

30. Area array photosensor

30R. Red area array photosensor

30G. Green area array photosensor

30BG. Blue-Green area array photosensor

30B. Blue area array photosensor

32. Dichroic filter

34. Dichroic mirror

36. Beamsplitter

38. X-cube beamsplitter

40. Area array photosensor with red and blue color filter array

42. Area array photosensor with green and blue-green color filter array

46. Area array photosensor with red and green color filter array

48. Area array photosensor with blue and blue-green color filter array

60. Area array photosensor with multicolor color filter array

100. Color gamut of human eye

102. Motion picture film color gamut

104. NTSC TV color gamut

106. Four sided polygon

108. Blue polygon vertex, 442nm

112. Blue-green polygon vertex, 488nm

114. Green polygon vertex, 515nm

116. Red polygon vertex, 649nm

120. Image acquisition unit

122. Control logic processor

124. Image data storage unit

126. Signal processing unit